INVESTIGATION INTO THE ATTENUATION OF SEISMIC IMPULSES IN DIFFERENT SOIL TYPES

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THESIS

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ABSTRACT

A review of research indicates that the attenuation of seismic impluses is a complex function of such factors as moisture, soil thickness, substrata homogeneity, substrata consistency, and vegetation. The problem encountered when seismic devices are employed in a tactical situation is the prediction of ranges of detection for different soil types without resorting to soil samples, compression tests, etc. A knowledge of the seismic characteristics or the ranges of detection in various soil types would be very beneficial when employing seismic devices. This thesis will show a relationship, useful for prediction, between the attenuation properties and the range at which a test signal is first detected at a preset level.

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I. INTRODUCTION

The Viet Nam War brought about drastic changes in the tactics associated with conventional warfare. No longer was the United States fighting conventional enemy forces along well defined battle fronts. The war that the United States was in was against an elusive guerrilla. He fought when he wanted to, was not tied down to any battle lines, and could cover vast areas of land with his mobility. Without any battle lines, control of the entire countryside by conventional forces would not only be uneconomical, but would require far more forces than were available to the commanders at that time.

To fill the void created by the lack of sufficient forces to cover the entire countryside, electronic surveillance and intelligence gathering equipment were developed. Because of their immediate need in the battlefield, they were developed, produced, and employed with very little time for testing or development of a doctrine for their implementation. With the disengagement of U.S. Forces from Viet Nam and the realization that doctrine for the employment, and knowledge of the sensors operating characteristics was not complete, there is now a great deal of interest by all the services of the Armed Forces to develop a doctrine for their employment and learn more about the sensor's operating characteristics.

A. UNATTENDED GROUND SENSORS

1. Types of Unattended Ground Sensors

Sensors are classified by types as to the type of target they detect. The four commonly used unattended ground sensors are: (1) Seismic, (2) Magnetic, (3) Infared, (4) Acoustic.

The seismic unattended ground sensor detects ground vibrations such as from men or moving vehicles. Seismic sensors are medium ranged sensors with a detection range depending on soil type. Seismic sensors, when used in strings of two or three, provide information on target speed and direction.

Magnetic detectors are used to detect metal such as rifles, trucks, etc., passing through the field of the detector. Magnetic detectors have a very short range and detect only metallic targets.

Infared detectors detect changes in heat, such as a man or a hot engine. They have a directional field of view rather than being omnidirectional. They can be used to determine the approximate number of intruders present.

Acoustic detectors are keyed on noise. They have a large audio listening range, but must be in an area where noise is likely to be made by intruders (i.e. low ambient background noise). They are used mainly as a listening device and indicate the presence of noise or conversation.

2. Uses of Unattended Ground Sensors

The major limitation on the use and employment of unattended ground sensors is the user's imagination. Some examples of the way sensors were employed in Viet Nam are as follows:

a. Border Surveillance. Sensors were employed at points of entry that were most likely to be used by the enemy and where other methods of surveillance were not feasible.

b. Monitoring Water Crossings. At water crossings the enemy is naturally canalized. Sensors placed at these locations because of

the likely presence of the enemy were used to determine direction and trends of enemy movement.

c. Monitoring Trails. Sensors were used to reveal enemy traffic patterns which could be used to locate assembly or rest areas.

d. Monitoring Enemy Base Areas, Bunker Complexes and Caches to Determine Reoccupation. Sensors were used to determine when the enemy reoccupied a base camp or a bunker comples.

e. Abandoned Friendly Night Defensive Positions and Bases. Since a common enemy tactic was to enter abandoned friendly positions to gather usable material or occupy the prepared bunkers and trenches, sensors were planted in such areas to indicate enemy movement into these areas.

f. Monitoring Enemy Food Crops. In those areas where the destruction of enemy food crops was not feasible, sensors were planted to indicate any attempt by the enemy to harvest their food crops.

g. Providing Security and Early Warning. Sensors were employed to assist in alerting friendly positions against surprise attacks.

B. STATEMENT OF THE PROBLEM

One of the problem areas when using seismic sensory devices has been the variation of ranges of detection of a target in various soil types. The seismic devices are binary type detectors, in that they only indicate the presence or absence of a signal. They are not able to determine the type of target that is present, but only that a signal of magnitude large enough to be recorded is present. The

classification of targets by types would be easier if the seismic characteristics of that particular soil were known. The problem with the soil is that sound impluses attenuate at different rates for various types of soils causing varying ranges of detection. This thesis investigates the relationship between range of detection and soil type. By knowing this model, then it would be an easy matter to conduct a rather simple field test to determine the seismic characteristics of any soil type.

C. BENEFITS OF THE STUDY

The most important benefit from this study is that it will provide a better understanding of how the ranges of detection vary from one soil type to another. Furthermore, it will provide some information on the attenuation of seismic impluses in various soil types. Another benefit is that it may provide a rather simple method of determining the ranges of detection of a single man in various soil types. With this knowledge, the device could be placed at a certain distance or a particular gain setting so specific targets will not be detected. Another benefit is that it allows that complicated procedure as outlined in (5) for determining the seismic characteristics of a particular soil type be discarded and replaced by the rather simple field test used in this thesis.

II. GENERAL CONCEPT OF THE STUDY

The development of the model for seismic characteristics of the soil required that several assumptions be made and that some testable hypotheses be conjectured. Furthermore, a criterion for determining whether a detection had or had not occurred was required. The assumptions used, the hypotheses conjectured in this study, the statistical tests used in the analysis of data, and the underlying rational for their use are explained in this chapter. The criterion for determining detection is also explained.

A. ASSUMPTIONS AND HYPOTHESES

1. Seismic Characteristics of the Soil

It was assumed that the soil in which the seismic devices were planted was locally homogeneous. By homogeneous, it is meant that those factors, which affect the transmission of seismic impluses through the soil, are constant in the area that the test is being conducted. Some of those factors which affect the transmission of seismic impluses through the soil are moisture, soil thickness, substrata homogeneity, substrata consistency, and vegetation. With this assumption it was hypothesized that in a homogeneous soil, the angle or direction of approach by a target to the seismic device did not significantly change the range of detection.

2. Characteristics of the Seismic Devices

The most important assumption that must be made about the seismic device is that it is such a simple device that it aggregates all of the factors that seismic attenuation is a function of. The

device is not able to determine to what degree the rate of attenuation is a function of soil type, vegetation, moisture, etc., but considers it a function of all of them and considers the rate of attenuation as a single rate. With the above assumption, two hypotheses must be made about the devices. The first hypothesis was that all seismic devices of one particular type have the same operating characteristics. The second hypothesis was that the seismic characteristics of different soil types could be represented by a single parameter.

B. CRITERION FOR DETERMINING DETECTION

One point of contention in most prior experiments dealing with seismic devices was the criterion used for detection in the experiment. Many criteria have been felt too demanding (4). This appears to have been done in an effort to reduce the false alarm rate.

The criterion used in this experiment, where the ranges of detection of a target from a seismic device were desired, was that the device must be transmitting a signal seventy-five percent of the time. This appeared to be a realistic criterion when the experiment was actually run. A fifty per cent criterion did not appear to be critical enough and to attempt to make the criterion any harsher seemed overly severe.

C. STATISTICAL TESTS EMPLOYED

1. Analysis of Variance

Analysis of variance (ANOVA) is a technique used to investigate the effects that a number of factors have on the outcome of an experiment. In a two-way analysis of variance there are two variables (factors) which influence the outcome of an experiment. Here, the analysis of

variance test allows the isolation of the effects of each of the two factors as well as the interaction of the two to see how each factor affects the outcome of the experiment and which of the factors cause a significant difference in the means of the data. The two-way analysis of variance can be easily expanded to a four-way analysis of variance where there are four factors that could cause a significant difference in the means of the data.

The only assumptions that are needed when using the analysis of variance test is that there be independent observations from normally distributed populations with equal variance.

2. <u>Linear Regression</u>

Linear regression is a method for fitting a functional relation to data which appear to be linearly related. Using the method of least squares, the points are fitted with a linear curve. The curve estimated by the above method is used for predicting or estimating, and the squares of the difference between the true values and the predicted values is a minimum! In linear regression, the slope and intercept are estimated parameters. In the analysis of data, we compare the slopes of the several regression lines to determine statistical differences.

3. <u>Correlation Coefficient</u>

The correlation coefficient is a measure of the strength of the linear relationship between two variables. It is, though, a mathematical measure, and devoid of any cause or effect implications.

The correlation coefficient associated with a simple linear regression is easily obtained from the regression analysis. The coefficient ranges from -1 to +1, where -1 represents perfect negative linear

association in the sample and +1 represents perfect positive linear association in the sample. A value of 0 is interpreted to mean no association between the two variables.

III. DESCRIPTION OF MATERIAL

The seismic device that was used in this experiment was the patrol seismic intrusion device (PSID). The PSID, AN/GSQ-151, is a hand emplaced, expendable sensor designed to detect the seismic distrubances created by moving personnel and vehicles. The Anti-Intrusion Alarm Set made by the Dorsett Electronics Company is composed of five major units; four PSID's or sensor units, one receiver set; and minor components (headphone, carrying cases, and batteries). (See Figure 1)

A. THE DETECTOR SET

Each sensor is a sealed, self-contained, waterproof pulse-amplitude-modulated transmitter in a molded plastic case. Attached to the plastic case is a flexible whip type steel antenna, and a geophone on an eight foot cable. A six position switch on the plastic case allows an off position and five gain setting positions. The lower the gain, the lower the sensitivity of the device.

The four detector sets all operate on the same radio frequency but transmit four different code pulses with different audio tones (to increase discernability between detectors). Each detector case is marked with a number of raised dots which corresopnds to the number of pulses that that particular set transmits. The individual pulses are seventy milliseconds in duration with an interval of fifty milliseconds between pulses. Groups of pulses have at least a 100 millisecond period between them. Once the detector has transmitted a signal, it will not accept another signal until at least 100 milliseconds have elapsed. Figure 2 compares the pulse shape of the four different detectors.

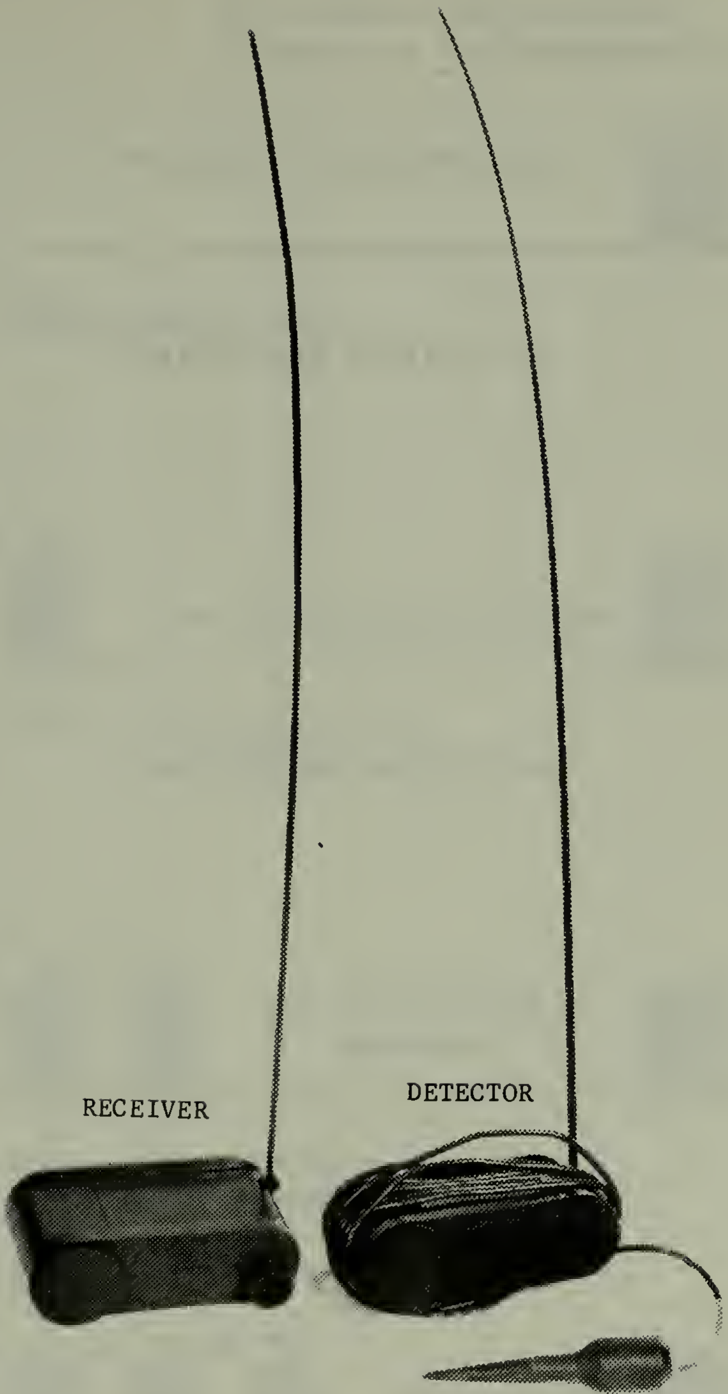


FIGURE 1. DETECTOR AND RECEIVER SET

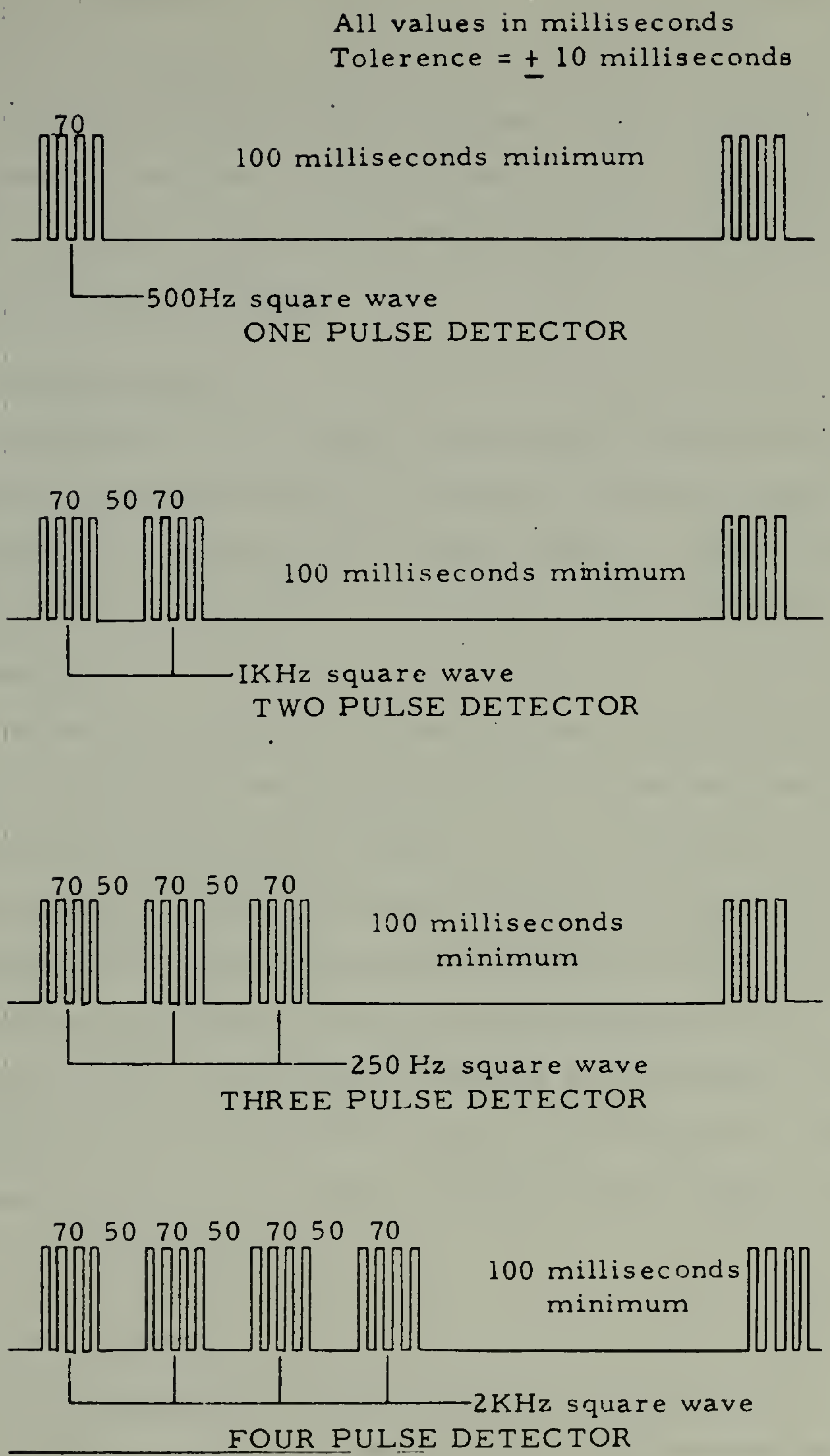


FIGURE 2. DETECTOR MESSAGE FORMAT

The geophone is the device that actually senses movement of personnel and vehicles. It in turn sends a signal to the detector which transmits a signal in the respective message format corresponding to that particular device.

B. THE RECEIVER SET

The receiver set is a sealed, self-contained, waterproof, pulse-amplitude-modulation receiver in a molded plastic case. The receiver is controlled by a single on-off switch. Also attached to the case is a flexible whip style antenna. An external headphone is required for listening.

The receiver operates on the same frequency as the detector sets and can be used with any one or all four devices. When the receiver picks up the transmitted signal from a detector set, it converts it to a pulsed audio tone which is heard through the headset. An experienced receiver operator will be able to determine which detector device is transmitting by the tone and number of pulses. An inexperienced receiver operator will have trouble because groups of pulses are superimposed on each other if more than one detector set is actuated simultaneously. Distinguishing between detector sets is further complicated by the absence of a recording device for the signals.

C. OTHER EQUIPMENT

1. Califone Portable Cassett Tape Recorder Model AV80

This solid state, portable, cassette tape recorder was used in the experiment to record the audio signals from the receiver set. The microphone of the tape recorder was taped to the receiver headphone.

2. Brüel Kjaer, Strip Chart Recorder

This strip chart recorder, which has a continuous moving tape was used to transfer the recorded audio signals from the tape recorder to a strip of the moving tape. The strip chart recorder has one recording pen which can either be used in the automatic or manual mode. Selection of the mode used is made by a switch on the top of the case.

IV. EXPERIMENTAL PROCEDURE

The experimentation was divided into two segments. The first segment was carried out at one location using twelve of the detector sets and three receiver sets. The purpose of this segment of the experiment was to verify that there is no significant difference between detectors and receivers and that the range of detection is independent of the angle of approach of the target to the detector. (under reasonable homogeneous soil conditions). If this could be verified then the second segment of the experiment could be conducted using fewer detectors and only one angle of attack, thus reducing the amount of experimentation required.

The second segment of the experimentation was to obtain ranges of detection at each of the five gain settings from various locations in the Monterey-Salinas-Big Sur area. Five different locations were tested, each using two devices. Three tests using two devices were conducted in the Torro Park area, one test was conducted in a creek bed behind Torro Estates, and one test was conducted near Point Sur.

One problem that arose when the detector signals on the tape recorder were converted to indications on the continuous moving strip of the strip chart recorder was that the recorded signal impluses were not of the magnitude necessary to activate the strip chart recorder in the automatic mode. However the recorder had a manual mode, the use of which posed no problems.

A. FIRST SEGMENT

Prior to the actual running of the experiment the test site was set up in the following manner. A geophone from a detector set was embedded in the ground with the spike down and within twenty degrees of the vertical, regardless of the terrain contour. From that point, two distances of thirty and sixty meters were measured off in six directions with approximately sixty degrees between directions. Prior to the beginning of the experiment, test runs were conducted at each gain to determine at what distance (either thirty or sixty meters) each run could begin. This was done to reduce the distance that the experimenter had to walk (providing he started outside the range of detection). In most cases, gains one, two, and three used the thirty meter starting point, and gains four and five the sixty meter starting point.

In this segment, a run was conducted at each gain on every device from all six directions for a total of three hundred and sixty runs, The same target was used throughout. Each data run consisted of the target, a man wearing loafers, proceeding from each of the starting points toward the geophone at a rate of approximately sixty meters per minute. The tape recorder was carried by the target on each run. At the beginning of each run, the target designated on the recorder tape. the run, the gain, the starting distance, and gave a command indicating commencing to walk. When the target entered the detection area and was detected, the receiver received the signals from the detector and converted these to audio pulses which were recorded by the tape recorder. Upon reaching the geophone, the target designated the completion of the run.

B. SECOND SEGMENT

After an analysis of the data taken during the first segment of the experiment, the second segment of the experiment was to obtain ranges of detection at the five gain settings for various soil types. From the analysis of the data obtained from the first segment, it was verified that there was no significant difference between detectors, so to reduce the amount of data collected at each test site, only two devices were used at each of the test sites. The devices that were used were from the same Anti-Intrusion Alarm Set and the number two detector set was used at every test site as a control. The other three detector devices in the set were alternately used as the second device at each of the test sites.

The test area at each site was set up in the same manner as the site in segment one, except that only one direction of approach was used. The using of only one direction of approach was necessary in some of the various test sites which were not large enough to allow angles of approach from the other five directions. In the Big Sur area and the Creek Bed at Torro Estates, only one direction of approach was possible. Although the analysis of the data in segment one did not statistically support the hypothesis that the angle of approach of the target to the detector was not significant, we shall show that the angle of approach did not cause a really significant difference in the mean ranges of detection. After the trial runs had been completed to determine if the range of detection for the first three gains was under thirty meters and the other two gains range of detection was under sixty meters, six runs at each gain were made for each of the two devices. This gave a total of sixty runs for each test site.

C. DATA CONVERSION

1. Tape Recorder to Strip Tape

With the experiments recorded, it was necessary to convert this audio record to visual signals on a strip chart. Unfortunately the tape recorder did not provide the external speaker required for the Brüal Kjaer Strip Chart Recorder to operate in the automatic mode. Thus it was necessary to activate the indicator pen on the strip chart by using the manual control on the recorder.

While the tape recorder played back each of the runs and the strip chart was moving at the rate of ten mm/sec., the beginning and end of each run was marked at the commands "Begin" and "Stop" from the tape recorder. During each run, each group of pulses was recorded by pressing the manual pen indicator. At the beginning of each run, the strip chart was marked with the appropriate information. See Figure 3 for a typical tape.

2. Strip Tape to Measurements

After all the runs had been recorded on the strip chart, two measurements were made on each tape. The first measurement was the distance between the two marks that indicate the start and end of the run. The second measurement was from the point where detection was made to the end of the run (Figure 3). A third quantity used, although actually not a measurement, was the range that particular run began, which was transcribed from the recording. All measurements were measured to the nearest .5 millimeter.

As noted before, we adopted a criterion for determining whether detection had or had not occured. This criterion was that the

FIGURE 3. SAMPLE OF STRIP TAPE USED IN GETTING MEASUREMENTS

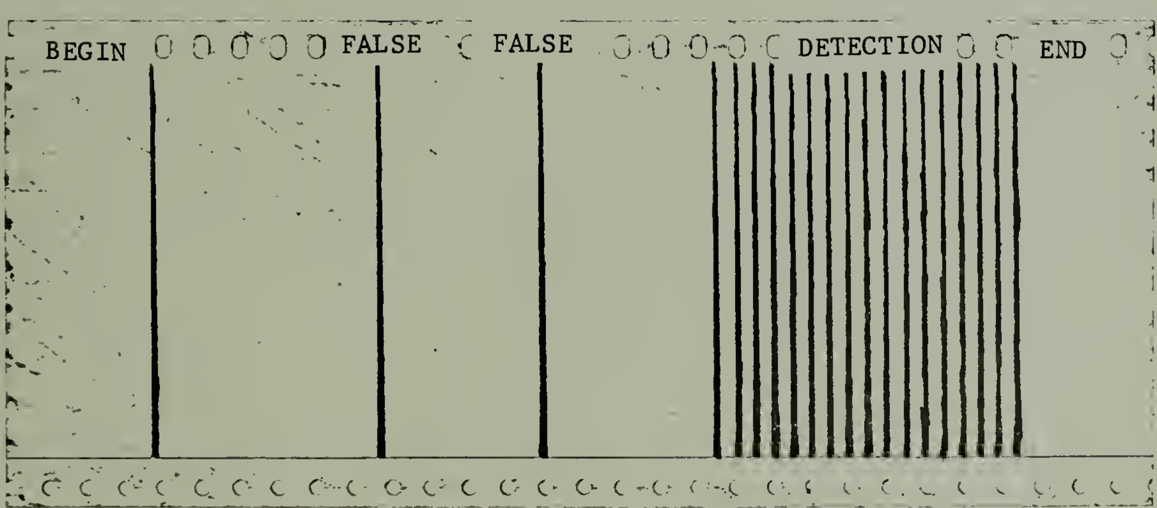


FIGURE 4. SAMPLE STRIP TAPE WITH FALSE ALARMS

detector must have sent a signal 75 percent of the time, or no detection had occurred. With this criterion, the false alarms were relatively easy to identify. They appeared as a lone spike followed by no indication for a few steps. When detection did occur, indications were almost continuous. Figure 4 demonstrates the use of this criterion.

3. Measurement to Ranges of Detection

A simple computer program was written to convert the measurements taken off the strip chart tape to ranges of detection. This was possible for every run, we knew the distance traveled over the ground, the length of the tape which corresponded to this deistance and the length of the tape which corresponded to the distance to the detection point. Assuming constant target velocity reduced the problem to a simple ratio. The ranges of detections thus found, in each of the locations are shown in appendix A.

V. ANALYSIS OF DATA

The gathered data was analyzed in two segments, corresponding to the two segments of the experiment. The first segment analyzed the data taken during the first segment of the experiment to determine if there were any significant differences between either the devices used in the experiment or the angle of approach of the target to the detection device. The second segment of the analysis was divided into five steps and analyzed the data taken during the second segment of the experiment.

Appendix A contains all the data obtained in the experiment. This data is presented in both tabular and graphical form. Table 5-1 shows the mean ranges at each gain setting and direction as obtained in segment one. Table 5-2 shows the mean range of detection at each gain setting for the different locations tested during the second segment of the experiment.

A. SEGMENT ONE

To test the hypothesis that there was no significant difference between the different detectors, the angles of approach of the target to the detection device, and the Anti-Intrusion Alarm Sets, a four-way analysis of variance was used on the full data. A computer program designated BIMED 02V was available for this. This program is one of a series of library programs designated by the Health Sciences Computer Facility, UCLA (1). The first variable, which was the Anti-Intrusion Alarm Set, had three levels because three different sets were used. The second variable was the direction of approach by the target to the detector. In this case, there were six directions or six levels. The

TABLE 5-1

MEAN RANGE OF DETECTION AT EACH GAIN SETTING

FOR ALL SIX DIRECTIONS OF APPROACH

(SEGMENT ONE - GOLF COURSE)

DIRECTIONS	MEAN RANGE OF DETECTION (METERS)				
	GAIN SETTING				
	1	2	3	4	5
1	3.08	12.35	20.01	33.23	48.62
2	3.12	9.38	22.55	34.47	47.44
3	3.34	14.81	22.56	36.19	50.13
4	3.01	16.20	22.59	34.99	49.63
5	2.92	13.63	20.57	30.94	47.51
6	3.10	14.51	21.82	30.94	50.36

TABLE 5-2

MEAN RANGE OF DETECTION AT EACH GAIN SETTING

FOR ALL FIVE TEST SITES

(SEGMENT TWO)

LOCATION	DEVICE	RANGE IN METERS AT GAIN SETTING:				
		1	2	3	4	5
Big Sur	Common	1.60	3.70	11.23	17.44	38.86
Big Sur	Other	1.56	4.29	10.48	16.67	38.01
Torro Park Hard Pack	Common	11.09	14.76	20.82	33.19	47.48
Torro Park Hard Pack	Other	7.55	13.19	16.44	30.12	45.08
Torro Park Soft Pack	Common	7.48	17.70	23.43	30.44	40.38
Torro Park Soft Pack	Other	6.22	13.09	20.35	27.60	35.98
Torro Park Sand	Common	3.085	7.67	15.52	21.48	28.12
Torro Park Sand	Other	2.77	6.24	13.60	19.17	25.73
Creek Bed	Common	1.77	2.94	10.39	14.42	24.29
Creek Bed	Other	1.34	3.94	9.49	13.08	24.94

third variable was the gain setting of which there were five levels corresponding to the five gain settings. Of course, this variable was expected to cause significant differences in the ranges of detection. The last variable was the specific detector number and there were four levels of this variable corresponding to four different detector devices in each Anti-Intrusion Alarm Set.

Table 5-3 summarizes the results of the four-way analysis of variance. That the different Anti-Intrusion Alarm Sets or the four detectors sets did not cause any significant difference between the mean ranges of detection is shown by the F-test values on Table 5-3. However, there was a statistically significant difference between various angles of approach, as shown by the F values.

Trying to explain the reason for this difference at the various angles of approach, we compared the average range of detection for each of the angles of approach at each of the gain settings as shown by Table 5-1. By looking at this table, it was very apparent that directions three and four had significantly higher mean ranges of detection than directions one, two, five, and six. Then we realized that these two directions were closest to a highway and the Monterey Fair Grounds while the other four directions were away from the highway and towards an area of no vehicular activity. Tentatively, we then concluded that the significant difference between mean range of detection could be attributed to the difference in noise level for the various directions. Furthermore, comparing the absolute differences of the mean ranges as given in Table 5-1, we noted that in four out of the five cases, the absolute differences was less than three meters. In three cases the

TABLE 5-3

RESULTS OF FOUR-WAY ANALYSIS OF VARIANCE

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARE	F-RATIO
ALARM SETS	2	16.405	8.2026	1.3010
DIRECTIONS	5	298.883	59.776	9.4812
GAIN SETTINGS	4	91064.166	22766.039	3610.968
DEVICE NUMBER	3	45.462	15.154	2.40364
ERROR	120	756.562	6.304	
TOTAL	359	94160.875		

ALARM SETS: $F(2,120)=2.35$ at $\alpha = .10$ inplies not significant

DIRECTIONS: $F(5,120)=4.45$ at $\alpha = .001$ implies significant

DEVICE NUMBER: $F(3,120)=2.68$ at $\alpha = .05$ implies not significant

difference was less than two meters. These differences in distance were small when considering the degree of accuracy that would be required of the devices when employed in a tactical situation. Thus, it was decided to continue assuming there was no significant difference of mean ranges of detection between the various angles of approach of the target to the detector.

B. SEGMENT TWO

1. Step One

The underlying objective of this thesis was to compare curves plotting range of detection versus gain setting to see if they possessed some common shape. For example, if the curves were obviously quadratic, but could be made linear by some proper choice of variables, then the comparison of the curves would be a matter of comparing the slopes of the curves. If the transformed curves in fact could be proved to be parallel, then the curves could be said to be curves of relatively the same shape.

In our experiment, after several attempts, we found that plotting the natural logarithm of gain versus the natural logarithm of the range of detection showed an apparent linear fit. Regressions were estimated for each of the ten curves obtained by plotting the natural logarithm of range of detection versus the natural logarithm of gain setting. Each set of data was used twice. The first time, the data was in the form of individual observations of ranges of detection, of which there were thirty observations (six runs at each of the five gains) for each curve. In the second set, the dependent variable was the mean

range of detection for each gain setting (calculated using the six observations at each gain setting). In this case there were five observations for each curve. We felt that if the differences in the two approaches were small, then the regression estimated by using the mean ranges of detection could be used. This would make later calculations significantly easier.

After both the regressions were estimated the slopes and Y-intercepts of both methods were compared. See Tables 5-4 and 5-5. Since the differences between the slopes and the intercepts did not appear to be significant, it was decided that very little information would be lost using the means of the ranges of detection at a particular gain as opposed to the individual observations.

2. Step Two

Throughout the experiment, it was noticed that the opportunity for error in the ranges of detection was greatest at gains one and five. The error at gain one was likely because the ranges of detection were very small, and this did not allow the full use of the detection criterion. The error at gain five was likely because of the observed influences of background noise at this high sensitivity. In fact, in some areas, the wind caused sufficient noise to activate the devices at gain five.

To consider the possible effect of error at the high and low gain settings, the sensitivity of the regression to reduced weighting at these gains was investigated. Four separate weighting methods were used; (1) 0.3, 1.0, 1.0, 1.0, 0.3, (2) 0.5, 1.0, 1.0, 1.0, 0.5, (3) 0.8, 1.0, 1.0, 1.0, 0.8, (4) 1.0, 1.0, 1.0, 1.0, 1.0. After each regression

TABLE 5-4

COMPARISON OF THE SLOPE USING AVERAGED AND UNAVERAGED RANGES OF DETECTION IN ESTIMATING THE REGRESSION LINE

LOCATION	AVERAGED	NON AVERAGED	PERCENT DEVIATION
Big Sur Area	1.950	2.002	2.67
Big Sur Area	1.916	1.960	2.29
Torro Park Hard Pack	0.886	0.892	0.67
Torro Park Hard Pack	1.065	1.068	0.28
Torro Park Soft Pack	1.011	1.032	2.07
Torro Park Soft Pack	1.086	1.092	0.05
Creek Bed	1.777	1.684	5.23
Creek Bed	1.685	1.745	3.56
Torro Park Sand	1.399	1.429	2.14
Torro Park Sand	1.417	1.434	1.19

TABLE 5-5

COMPARISON OF THE INTERCEPT USING AVERAGED AND UNAVERAGED

RANGES OF DETECTION IN ESTIMATING THE REGRESSION LINE

LOCATION	AVERAGED	NON AVERAGED
Big Sur Area	0.277	0.204
Big Sur Area	0.307	0.243
Torro Park Hard Pack	2.252	2.241
Torro Park Hard Pack	1.904	1.898
Torro Park Soft Pack	2.063	2.031
Torro Park Soft Pack	1.823	1.812
Creek Bed	0.240	0.350
Creek Bed	0.357	0.271
Torro Park Sand	1.122	1.079
Torro Park Sand	0.976	0.944

the sum of the squares of the differences between the true and estimated ranges of detection at each gain were calculated for each of the weighting methods. A two-way analysis of variance showed no significant differences between the weighting methods. Table 5-6 summarizes the results of the two-way analysis of variance.

3. Step Three

Since there was no significant differences between the regressions estimated by the various weighting methods, it was decided to use the results with unweighted data. Brownlee (3) proves it is possible to compare the slopes of several regression lines to determine if they have the same slope and can be considered to be parallel. Testing the null hypothesis that the slopes of the individual lines are equal to the average slope of the separate lines, the statistic S_2^2/S_1^2 is used. S_1^2 is defined as:

$$S_1^2 = \frac{\sum_{i=1}^{k} (ni-2)Si_1^2}{\sum_{i=1}^{k} (ni-2)}$$

and S_2^2 is defined as:

$$S_2^2 = \sum_{i=1}^{k} (bi-\bar{b})^2 \sum_{v=1}^{ni} (Xiv-\bar{X}i.)^2$$

where ni was the number of points used to estimate the regression, S_{i1}^2 was the sample variance within each of the ten regression lines, bi was the estimated slope of each regression line, $\bar{b}$ was the average slope of the ten regression lines, Xiv was the individual observations used in estimating each regression line and $\bar{X}i.$ was the average X value of each of the regressions. In our case S_2^2/S_1^2 = 1.9028/.06576=28.93159 which

TABLE 5-6

RESULTS OF TWO-WAY ANALYSIS OF VARIANCE

CONSTRASTING WEIGHTING METHODS

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUMS OF SQUARES	MEAN SQUARE	F-RATIO
Test Location	9	16097.235	1788.581	3.424
Weighting Meth.	3	139.847	46.615	0.089
Error	160	85533.375	522.083	
Total	199	99984.250		

Weighting Method: $F(3,160)=2.08$ at $\alpha=.10$ implies not significant

under the null hypothesis was distributed as F(9,38). Clearly since F(9,38) = 2.00 at the α = .05 level, the null hypothesis of parallelism of the separate lines must be rejected.

4. Step Four

While rejecting the hypothesis that the ten regression lines were parallel, we noted that as the slope of the regression decreased, the average range of detection at gain three, the mid-range gain, increased. Gain three was used as the parameter to compare with the slope of the regression line because it was felt that the ranges of detection at gain three were more accurate than the ranges at the other gain settings. Table 5-7 graphically shows the relationship between slope and range of detection at gain three.

Regression analysis was used to see how the slope of the regression line obtained in Step one was correlated to the mean range of detection at gain three. Table 5-7 gives the resulting functional dependence. The computer programed BIMED 01R of the Health Sciences Computer Facility, UCLA (2) was used in the calculations. The resulting correlation coefficient was -0.91741 which indicates that the two variables are highly, but negatively correlated.

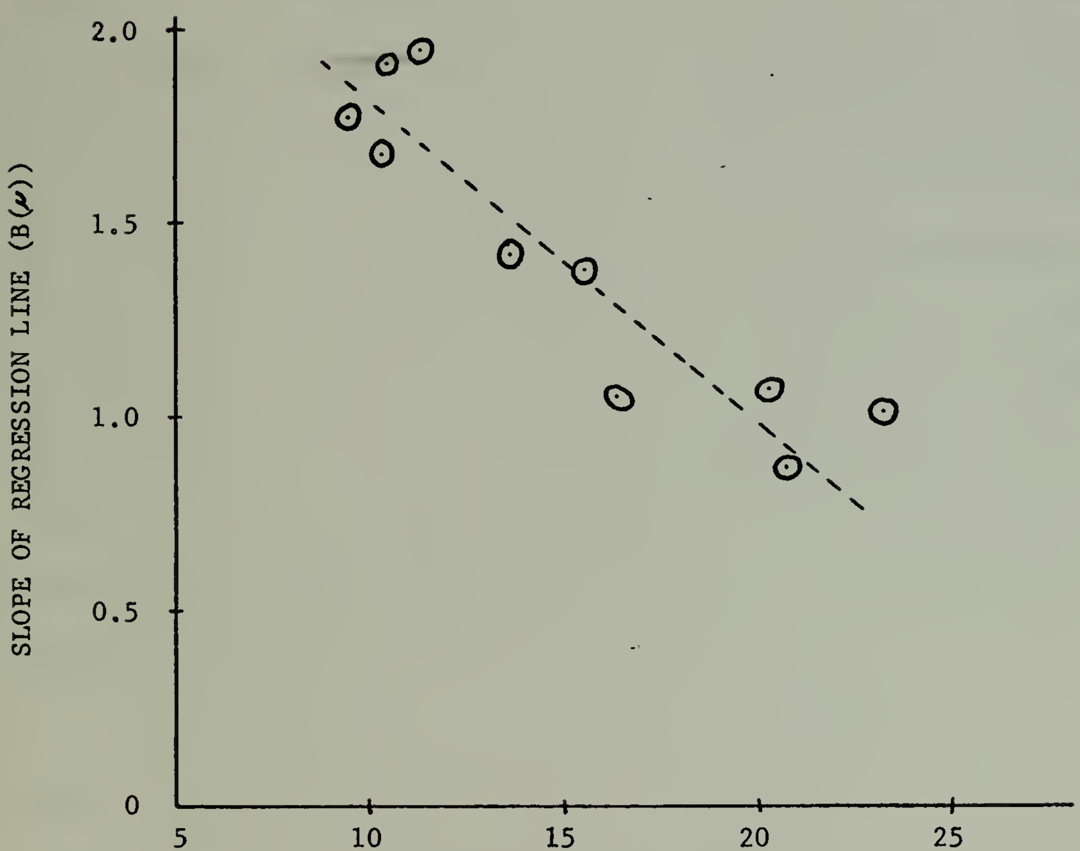
5. Step Five

From the previous step it was noted that there was a high correlation between the slope of the regression and the mean range of detection at gain three. This strongly supported our belief that the seismic characteristics of a particular soil can be characterized by a single parameter, the range of detection at gain three. (We believe

TABLE 5-7

PLOT OF SLOPE OF REGRESSION LINE VERSUS

MEAN RANGE OF DETECTION AT GAIN THREE



MEAN RANGE OF DETECTION AT GAIN THREE (μ)

ESTIMATED REGRESSION EQUATION

$$B(\mu) = 2.52992 + \mu(-0.07316)$$

CORRELATION COEFFICIENT

-0.91741

this possible because this device is sufficently simple that it aggregates all those factors affecting the attenuation of seismic impluses.) Using the relationship between this parameter and the slope of the regression it was easy to generate a table of predicted ranges of detection at all five gain settings depending on the range of detection at gain three. Table 5-8 is this table. Under the table is described the field test that would be used with the table and an explanation as to the use of the table. This table could be used in a tactical situation by the troops employing the type of device used in the experiment.

In order to obtain the estimated ranges of detection in the table, average ranges of detection at gain three of 5, 10, 15, 20, and 25 meters were used, and the slope for each of these ranges was solved for from Table 5-7. Knowing this slope, and using the range of detection at gain three to specify a point on the line uniquely determined the appropriate line. The formula used was as follows:

$$\ln(R_G) = \ln R_3 + (\ln G - \ln 3)B(\mu)$$

where:

R_G = detection range at gain G

$B(\mu)$ = slope from Table 5-7 corresponding to R_3

G = Gain setting

This formula then predicted ranges of detection at the four other gain settings.

TABLE 5-8

TABLE OF PREDICTED RANGES OF DETECTION VERSUS

GAIN SETTINGS UNDER DIFFERENT CONDITIONS

RANGE OF DETECTION AT GAIN THREE	PREDICTED RANGE OF DETECTION (Meters) At Gain: 1	2	3	4	5
5 Meters	1	2	5	9	15
10 Meters	1	5	10	17	25
15 Meters	3	8	15	23	31
20 Meters	6	13	20	27	35
25 Meters	12	19	25	31	36

HOW TO USE TABLE:

1. Emplant PSID and set gain to three.
2. Walk toward device from outside range of detection.and mark point of detection.
3. Measure distance from point of detection to the detector.
4. Find range of detection that is closest to your measurement and enter table at that point. Corresponding ranges of detection at the various gain settings correspond to area tested.

VI. CONCLUSIONS AND EXTENSIONS

The problem addressed in this thesis was the determination of how seismic signals attenuate in different soil types and how this knowledge could be tactically applied. The hypothesis conjectured about the similarity of devices was verified at a very high level of confidence. Although the hypothesis concerning the angle of approach of the target to the device could not be statistically justified, we accepted this hypothesis nevertheless for two reasons. First, the fact that the absolute variation of the mean ranges with direction was small, such that the difference was considered insignificant in a tactical application. Second, the fact that the ambient noise may have been directional, due to less than an ideal location. As a result, we were able to verify that the seismic characteristics of every soil type could be estimated by only one parameter, the range of detection at gain three, the mid-range gain.

It was shown, that as the slope of the estimated regression of the natural logarithm of gain versus the natural logarithm of the range of detection increased, the range of detection at gain three decreased. With the knowledge of this relationship between the slope of the estimated regressions, it was a simple matter to determine the ranges of detection for various ranges of detection at gain three. Table 5-8 is an example of a table that would be appropriate for the Monterey-Salinas-Big Sur area.

We concluded that the seismic device employed in this thesis was such a simple device that it aggregated all the factors that influence

the attenuation of seismic impluses. Consequently this device views the seismic characteristics of any soil as characterized by a single parameter. The impact of this conclusion was that by using the rather simple field test in Table 5-8, the ranges of detection for a particular soil, or a seismic characterization of that soil type, is known.

There are obvious extensions to this study that time and lack of different soil types prevented further investigation. One obvious extension would be to investigate how the seismic impluses of other targets, such as groups of men, trucks, bicycles, etc., are attenuated in different soil types. The other would be to see if the relationship that seemed appropriate in this area was appropriate in other areas where there existed soil types not found in this area.

APPENDEX A

GOLF COURSE

RANGE OF DETECTION

DEVICE NUMBER 1

SET 1			SET 2			SET 3		
RUN	GAIN	RANGE	RUN	GAIN	RANGE	RUN	GAIN	RANGE
1	1	3.06	1	1	2.33	1	1	3.77
2	1	3.40	2	1	2.67	2	1	2.92
3	1	4.97	3	1	2.95	3	1	3.19
4	1	2.82	4	1	2.60	4	1	2.53
5	1	3.21	5	1	2.63	5	1	3.32
6	1	4.01	6	1	3.27	6	1	2.44
1	2	19.30	1	2	11.20	1	2	11.95
2	2	10.23	2	2	8.92	2	2	6.92
3	2	17.28	3	2	13.94	3	2	14.29
4	2	17.79	4	2	17.36	4	2	12.27
5	2	14.37	5	2	8.92	5	2	14.81
6	2	17.35	6	2	15.68	6	2	11.17
1	3	21.18	1	3	19.00	1	3	19.68
2	3	26.77	2	3	23.77	2	3	21.48
3	3	22.68	3	3	22.06	3	3	23.02
4	3	25.61	4	3	21.50	4	3	20.55
5	3	20.35	5	3	20.86	5	3	22.44
6	3	23.40	6	3	23.88	6	3	21.50
1	4	32.45	1	4	31.76	1	4	32.25
2	4	34.67	2	4	31.39	2	4	35.56
3	4	42.84	3	4	31.62	3	4	33.98
4	4	41.63	4	4	34.40	4	4	39.59
5	4	32.29	5	4	32.48	5	4	31.66
6	4	28.30	6	4	30.19	6	4	30.00
1	5	46.49	1	5	49.03	1	5	50.03
2	5	53.89	2	5	49.89	2	5	46.19
3	5	55.10	3	5	47.78	3	5	52.64
4	5	51.38	4	5	50.60	4	5	43.66
5	5	49.35	5	5	45.59	5	5	52.40
6	5	54.45	6	5	53.12	6	5	51.09

GOLF COURSE

RANGE OF DETECTION

DEVICE NUMBER 2

SET 1			SET 2			SET 3		
RUN	GAIN	RANGE	RUN	GAIN	RANGE	RUN	GAIN	RANGE
1	1	3.28	1	1	2.53	1	1	3.02
2	1	3.22	2	1	3.25	2	1	3.17
3	1	3.73	3	1	3.37	3	1	2.84
4	1	4.32	4	1	3.00	4	1	3.05
5	1	2.35	5	1	3.17	5	1	2.85
6	1	2.63	6	1	4.77	6	1	3.38
1	2	11.03	1	2	10.23	1	2	14.12
2	2	10.17	2	2	12.72	2	2	7.93
3	2	16.54	3	2	15.04	3	2	11.24
4	2	15.34	4	2	15.92	4	2	19.66
5	2	13.39	5	2	17.53	5	2	16.42
6	2	13.06	6	2	15.41	6	2	15.35
1	3	21.67	1	3	20.37	1	3	20.98
2	3	24.16	2	3	18.13	2	3	22.43
3	3	24.25	3	3	22.31	3	3	23.72
4	3	22.41	4	3	21.44	4	3	25.79
5	3	22.11	5	3	20.89	5	3	21.55
6	3	18.82	6	3	23.11	6	3	23.63
1	4	34.14	1	4	36.58	1	4	34.03
2	4	33.98	2	4	40.47	2	4	38.21
3	4	35.61	3	4	40.84	3	4	36.12
4	4	31.84	4	4	34.92	4	4	36.47
5	4	31.45	5	4	30.46	5	4	26.77
6	4	25.84	6	4	30.74	6	4	36.57
1	5	50.03	1	5	42.67	1	5	50.10
2	5	49.19	2	5	43.94	2	5	43.66
3	5	51.43	3	5	46.19	3	5	52.40
4	5	52.89	4	5	46.95	4	5	46.49
5	5	41.60	5	5	51.43	5	5	51.21
6	5	48.71	6	5	46.95	6	5	51.38

GOLF COURSE

RANGE OF DETECTION

DEVICE NUMBER 3

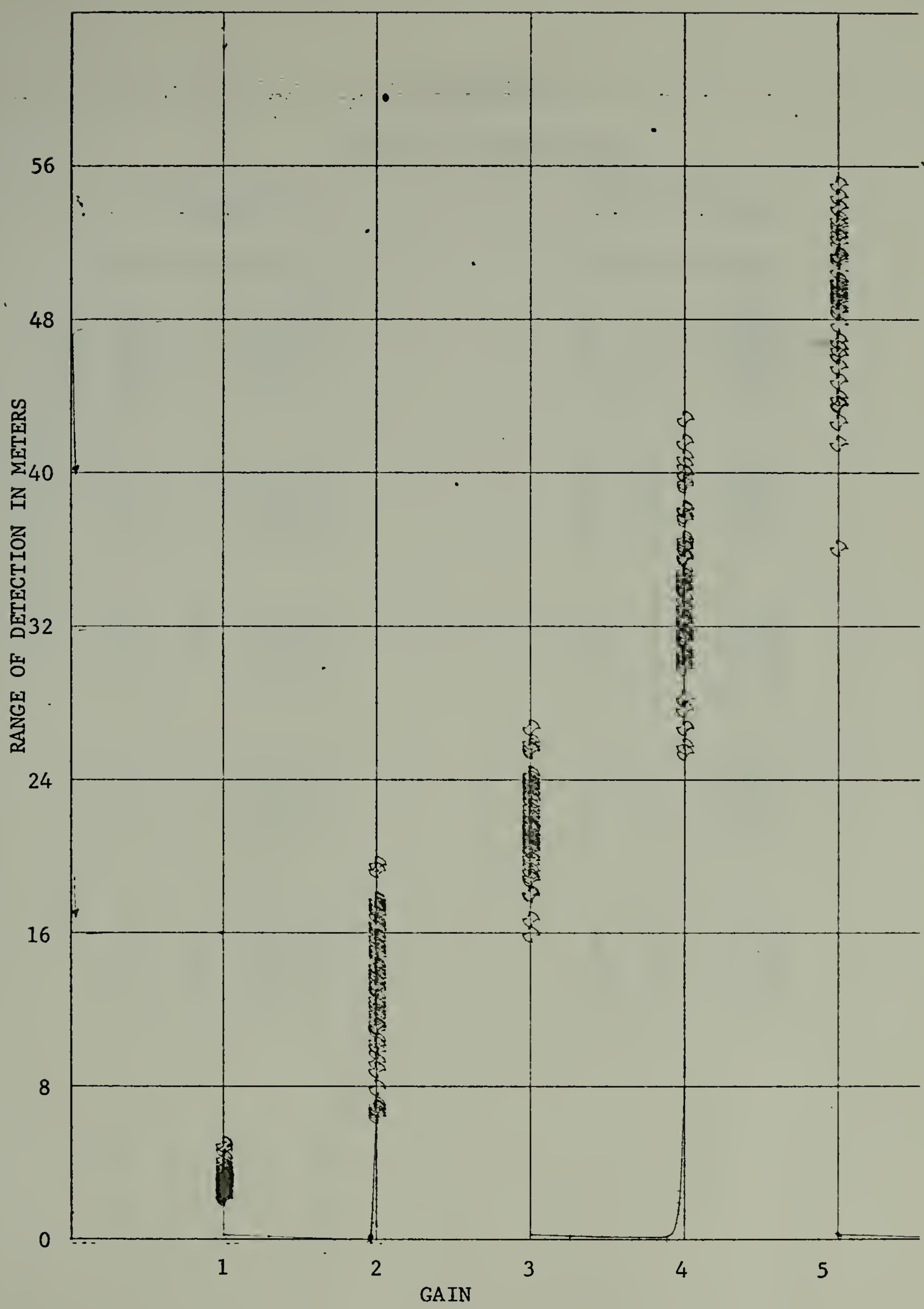
SET 1			SET 2			SET 3		
RUN	GAIN	RANGE	RUN	GAIN	RANGE	RUN	GAIN	RANGE
1	1	4.31	1	1	2.37	1	1	2.47
2	1	2.97	2	1	3.40	2	1	3.67
3	1	3.90	3	1	3.40	3	1	3.05
4	1	3.19	4	1	2.97	4	1	3.38
5	1	2.41	5	1	3.28	5	1	2.63
6	1	2.35	6	1	2.22	6	1	3.48
1	2	14.39	1	2	6.53	1	2	6.91
2	2	12.42	2	2	6.84	2	2	7.06
3	2	17.44	3	2	13.20	3	2	11.37
4	2	16.63	4	2	15.30	4	2	16.47
5	2	15.07	5	2	9.33	5	2	11.81
6	2	17.04	6	2	11.62	6	2	17.00
1	3	19.34	1	3	18.04	1	3	19.92
2	3	23.95	2	3	22.15	2	3	21.55
3	3	21.22	3	3	24.11	3	3	18.99
4	3	20.75	4	3	21.50	4	3	19.90
5	3	22.68	5	3	16.75	5	3	15.97
6	3	21.92	6	3	20.48	6	3	18.84
1	4	33.05	1	4	32.21	1	4	31.34
2	4	34.66	2	4	36.29	2	4	30.46
3	4	39.95	3	4	31.64	3	4	33.98
4	4	32.92	4	4	39.38	4	4	31.84
5	4	30.60	5	4	27.72	5	4	36.12
6	4	35.70	6	4	27.74	6	4	26.77
1	5	51.21	1	5	50.03	1	5	52.40
2	5	49.22	2	5	46.19	2	5	49.86
3	5	49.69	3	5	43.66	3	5	51.38
4	5	53.33	4	5	49.04	4	5	51.43
5	5	36.12	5	5	48.55	5	5	51.47
6	5	46.95	6	5	53.89	6	5	46.49

GOLF COURSE

RANGE OF DETECTION

DEVICE NUMBER 4

SET 1			SET 2			SET 3		
RUN	GAIN	RANGE	RUN	GAIN	RANGE	RUN	GAIN	RANGE
1	1	3.64	1	1	3.02	1	1	3.22
2	1	3.32	2	1	3.19	2	1	2.31
3	1	2.73	3	1	2.23	3	1	3.65
4	1	2.63	4	1	2.84	4	1	2.79
5	1	3.09	5	1	2.64	5	1	3.47
6	1	2.21	6	1	3.24	6	1	3.17
1	2	11.16	1	2	17.47	1	2	13.90
2	2	12.22	2	2	10.48	2	2	6.67
3	2	15.92	3	2	15.83	3	2	15.66
4	2	16.19	4	2	16.29	4	2	15.17
5	2	9.87	5	2	17.73	5	2	14.30
6	2	13.21	6	2	13.76	6	2	13.49
1	3	20.56	1	3	20.50	1	3	18.87
2	3	20.70	2	3	23.89	2	3	21.64
3	3	23.32	3	3	21.76	3	3	23.28
4	3	20.00	4	3	26.08	4	3	25.58
5	3	18.09	5	3	20.88	5	3	24.34
6	3	21.09	6	3	23.57	6	3	21.62
1	4	31.39	1	4	33.46	1	4	36.12
2	4	34.41	2	4	32.17	2	4	31.34
3	4	38.13	3	4	37.77	3	4	31.84
4	4	37.63	4	4	32.53	4	4	26.77
5	4	29.88	5	4	31.41	5	4	30.46
6	4	25.45	6	4	40.05	6	4	33.98
1	5	44.84	1	5	46.95	1	5	49.62
2	5	43.57	2	5	50.03	2	5	43.66
3	5	49.37	3	5	49.48	3	5	52.40
4	5	49.67	4	5	53.89	4	5	46.19
5	5	43.93	5	5	52.01	5	5	46.49
6	5	48.43	6	5	51.43	6	5	51.38



GOLF COURSE

CREEK BED

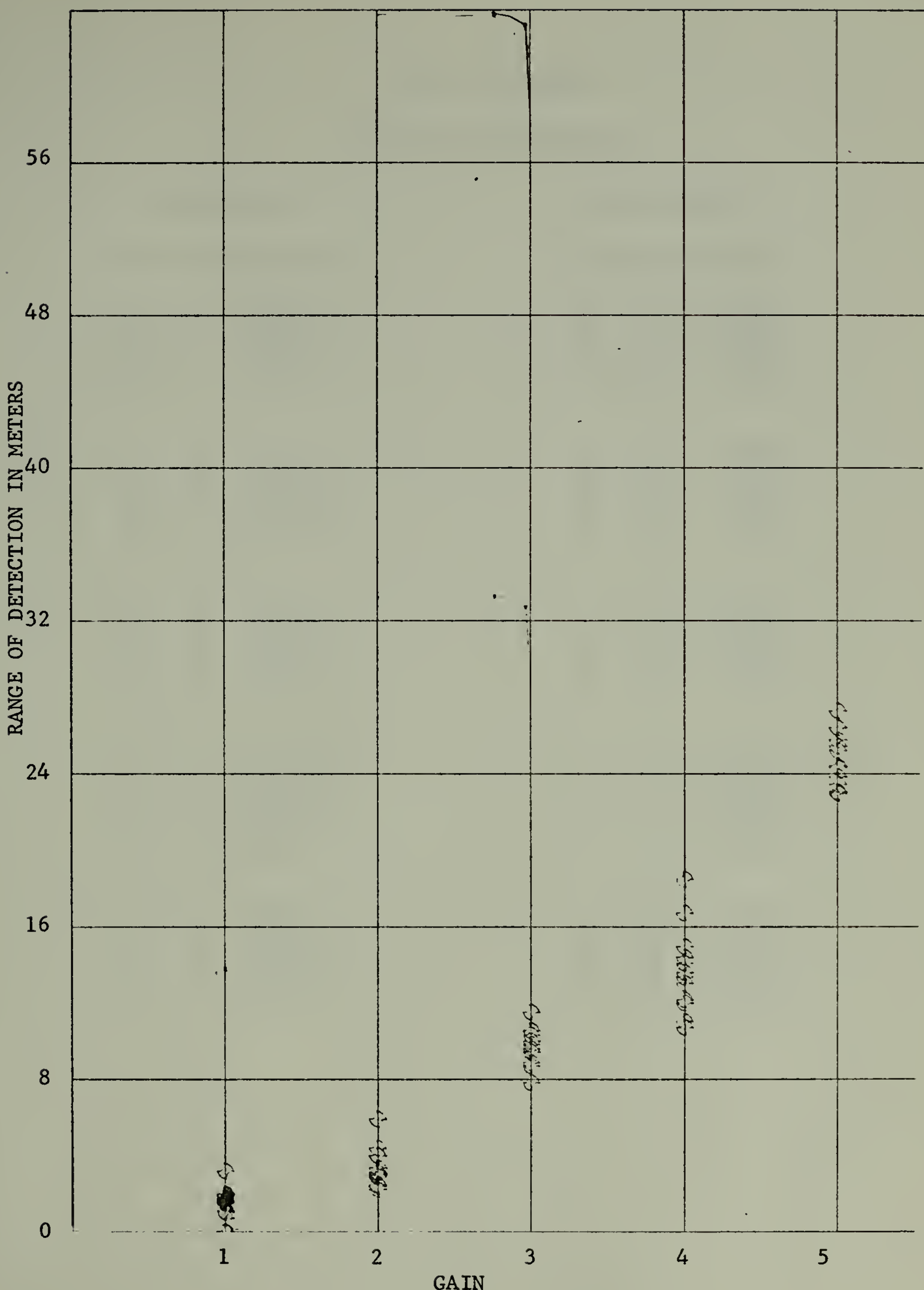
RANGE OF DETECTION

COMMON DEVICE

RUN	GAIN	RANGE
1	1	1.64
2	1	1.20
3	1	1.64
4	1	1.57
5	1	0.0
6	1	2.03
1	2	3.09
2	2	5.97
3	2	3.14
4	2	2.96
5	2	4.41
6	2	4.07
1	3	8.80
2	3	7.85
3	3	10.37
4	3	9.88
5	3	9.50
6	3	10.59
1	4	16.75
2	4	13.44
3	4	12.03
4	4	11.10
5	4	14.44
6	4	10.78
1	5	27.32
2	5	24.45
3	5	23.86
4	5	25.21
5	5	25.77
6	5	23.05

OTHER DEVICE

RUN	GAIN	RANGE
1	1	0.75
2	1	3.26
3	1	1.11
4	1	1.70
5	1	1.99
6	1	1.83
1	2	2.97
2	2	3.42
3	2	4.00
4	2	2.54
5	2	2.45
6	2	2.28
1	3	10.58
2	3	9.67
3	3	11.57
4	3	8.94
5	3	11.59
6	3	10.00
1	4	15.00
2	4	13.67
3	4	13.05
4	4	18.53
5	4	12.18
6	4	14.11
1	5	26.41
2	5	25.50
3	5	24.33
4	5	23.02
5	5	23.06
6	5	23.46



CREEK BED

BIG SUR AREA

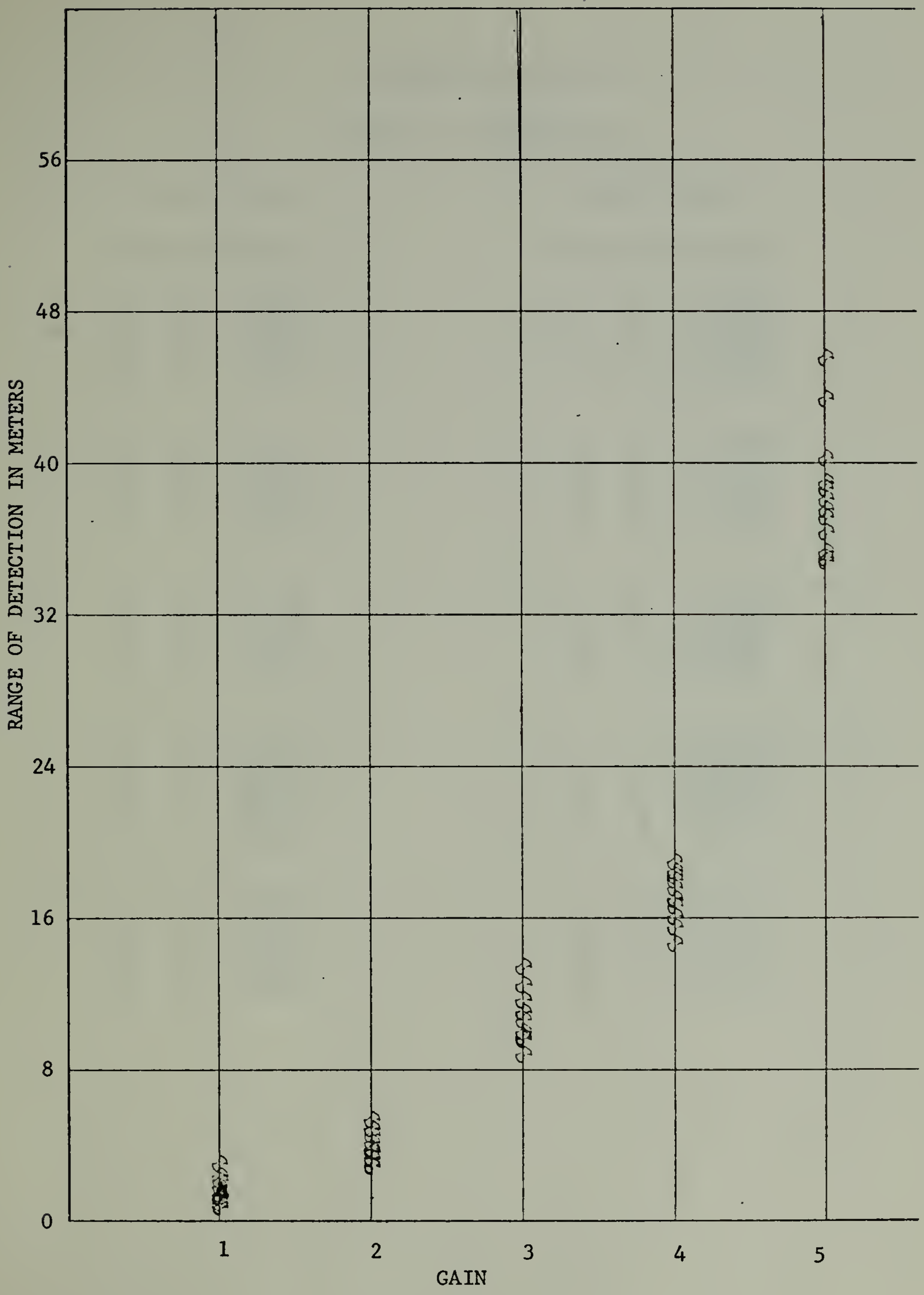
RANGE OF DETECTION

CCMMON DEVICE

RUN	GAIN	RANGE
1	1	1.45
2	1	1.31
3	1	1.25
4	1	0.97
5	1	1.31
6	1	3.11
1	2	3.85
2	2	5.37
3	2	4.89
4	2	3.42
5	2	4.90
6	2	3.35
1	3	9.62
2	3	10.00
3	3	9.81
4	3	11.72
5	3	10.71
6	3	11.06
1	4	19.03
2	4	14.65
3	4	16.09
4	4	16.68
5	4	18.02
6	4	15.57
1	5	40.27
2	5	45.56
3	5	35.34
4	5	34.99
5	5	34.81
6	5	37.13

OTHER DEVICE

RUN	GAIN	RANGE
1	1	1.44
2	1	2.43
3	1	0.88
4	1	2.21
5	1	0.79
6	1	1.90
1	2	3.80
2	2	3.71
3	2	2.98
4	2	4.21
5	2	4.61
6	2	2.91
1	3	11.05
2	3	12.54
3	3	13.52
4	3	11.74
5	3	8.82
6	3	9.72
1	4	17.64
2	4	18.56
3	4	18.30
4	4	17.05
5	4	16.10
6	4	17.04
1	5	38.65
2	5	38.16
3	5	43.37
4	5	39.02
5	5	36.39
6	5	37.58

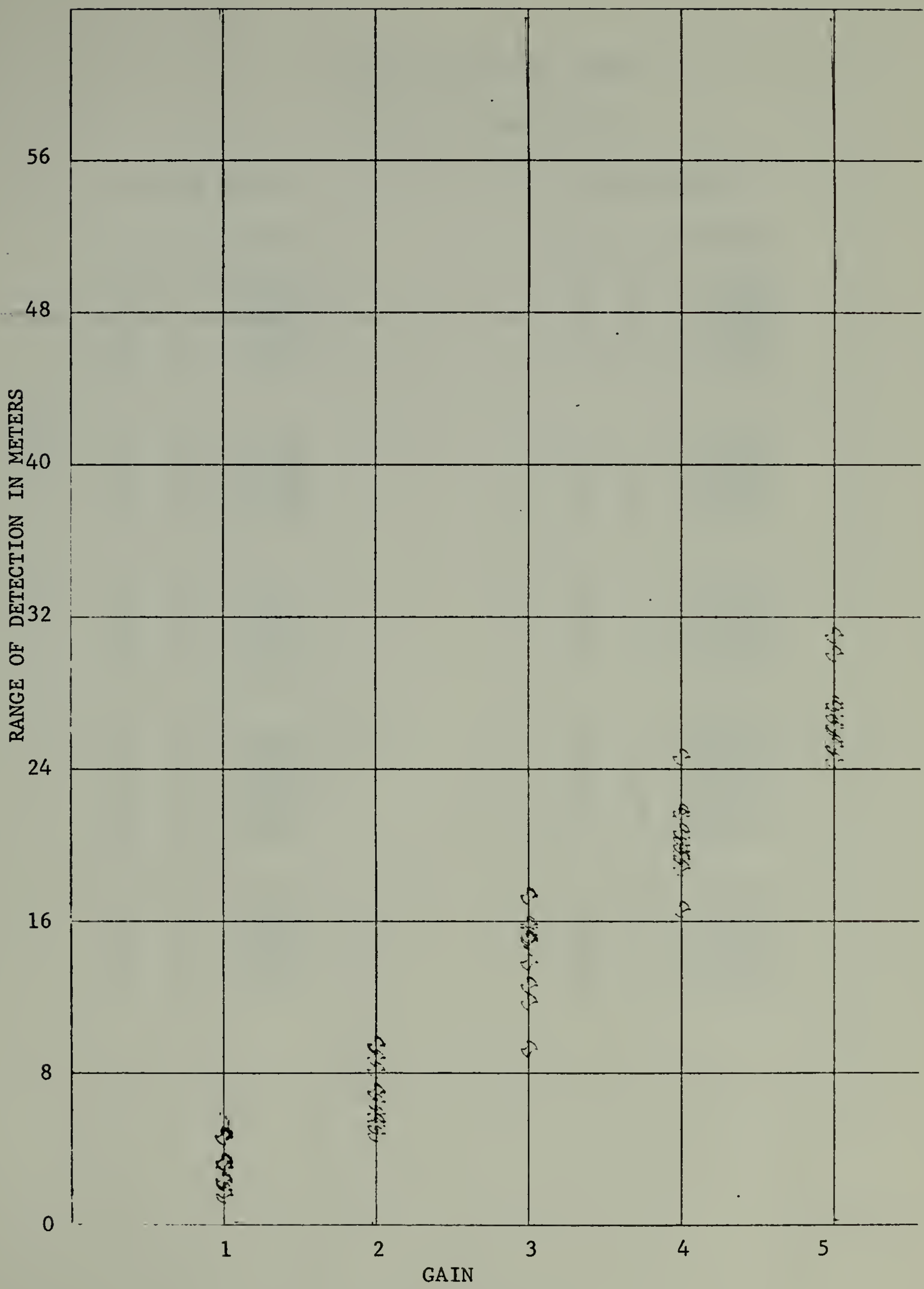


BIG SUR AREA

TORRO PARK SAND

RANGE OF DETECTION

COMMON DEVICE			OTHER DEVICE		
RUN	GAIN	RANGE	RUN	GAIN	RANGE
1	1	4.67	1	1	1.89
2	1	3.31	2	1	3.39
3	1	3.32	3	1	3.30
4	1	3.12	4	1	2.34
5	1	1.62	5	1	2.31
6	1	2.47	6	1	3.44
1	2	6.52	1	2	9.49
2	2	9.57	2	2	6.99
3	2	8.81	3	2	5.48
4	2	8.17	4	2	5.45
5	2	7.09	5	2	5.23
6	2	5.89	6	2	4.85
1	3	13.89	1	3	17.33
2	3	17.40	2	3	11.84
3	3	15.74	3	3	12.67
4	3	15.92	4	3	15.08
5	3	15.19	5	3	15.36
6	3	15.04	6	3	9.35
1	4	20.43	1	4	20.00
2	4	24.70	2	4	18.84
3	4	21.55	3	4	16.72
4	4	20.76	4	4	19.45
5	4	19.72	5	4	20.73
6	4	21.77	6	4	19.32
1	5	31.10	1	5	25.28
2	5	26.82	2	5	25.23
3	5	26.18	3	5	26.36
4	5	27.27	4	5	27.51
5	5	27.24	5	5	24.49
6	5	30.12	6	5	25.52

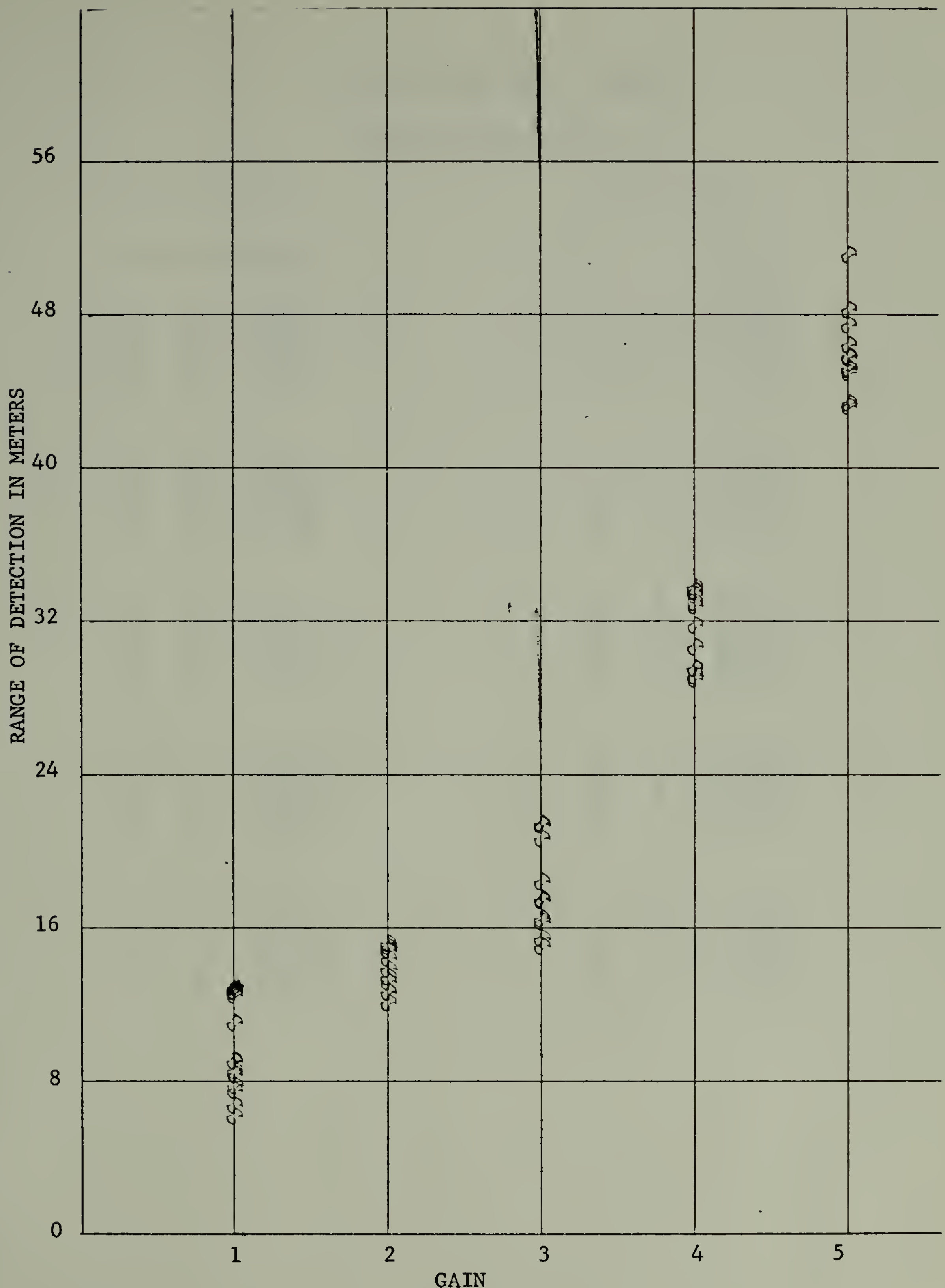


TORRO PARK SAND

TORRO PARK HARD PACK

RANGE OF DETECTION

COMMON DEVICE			OTHER DEVICE		
RUN	GAIN	RANGE	RUN	GAIN	RANGE
1	1	12.74	1	1	7.80
2	1	12.72	2	1	8.35
3	1	9.11	3	1	6.80
4	1	12.49	4	1	8.59
5	1	11.05	5	1	7.54
6	1	8.48	6	1	6.24
1	2	15.24	1	2	13.28
2	2	15.12	2	2	13.52
3	2	13.85	3	2	12.66
4	2	14.88	4	2	12.66
5	2	14.43	5	2	14.96
6	2	15.08	6	2	12.12
1	3	21.42	1	3	16.56
2	3	21.44	2	3	17.50
3	3	21.49	3	3	15.50
4	3	21.47	4	3	16.40
5	3	18.46	5	3	17.59
6	3	20.70	6	3	15.11
1	4	33.41	1	4	29.54
2	4	33.57	2	4	29.00
3	4	33.04	3	4	32.85
4	4	31.78	4	4	29.15
5	4	33.62	5	4	29.54
6	4	33.77	6	4	30.69
1	5	47.47	1	5	45.82
2	5	43.25	2	5	45.00
3	5	51.20	3	5	45.19
4	5	48.25	4	5	45.90
5	5	48.27	5	5	45.24
6	5	46.45	6	5	43.38



TORRO PARK HARD PACK

TORRO PARK SOFT PACK

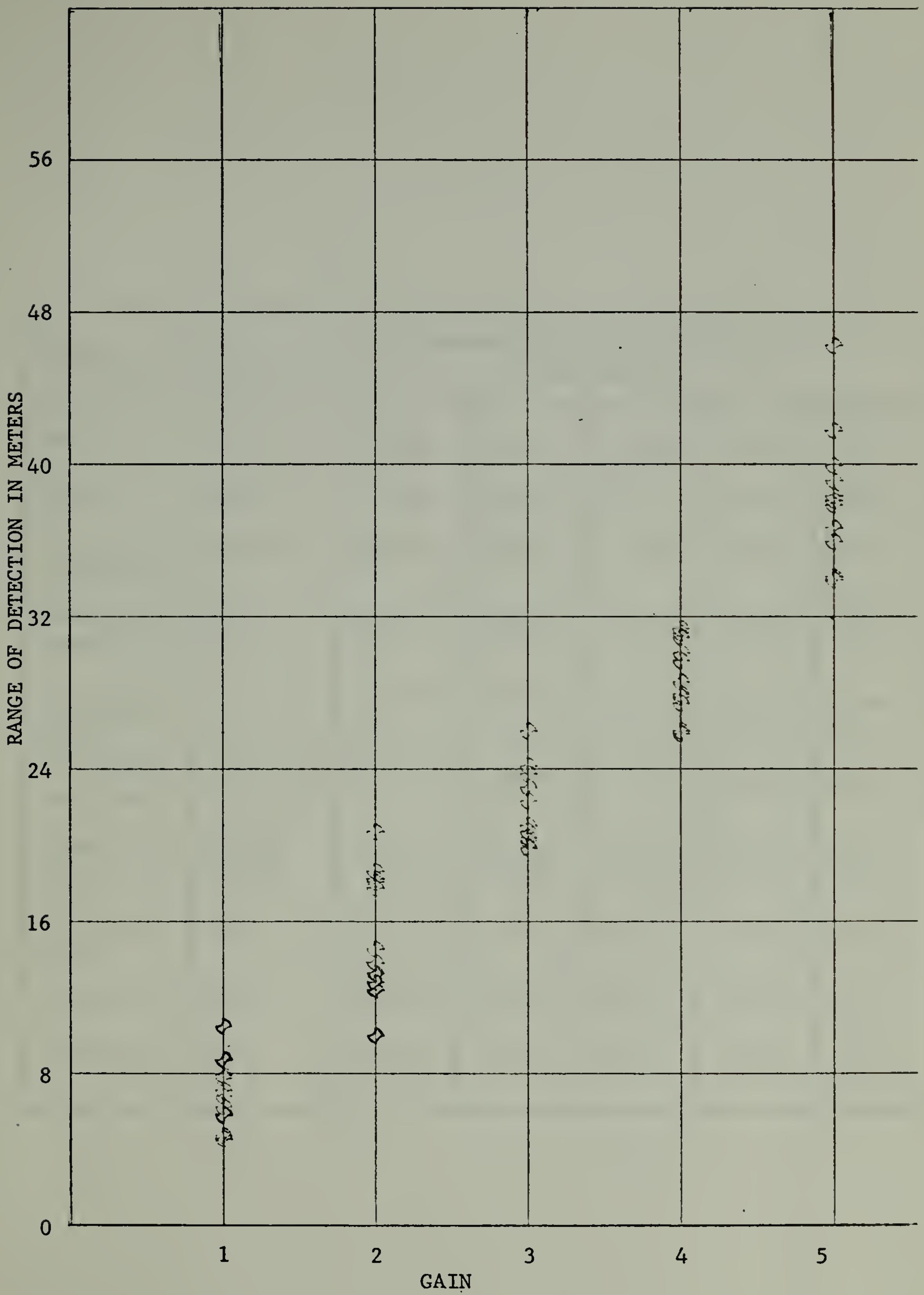
RANGE OF DETECTION

COMMON DEVICE

RUN	GAIN	RANGE
1	1	8.75
2	1	5.90
3	1	4.58
4	1	7.16
5	1	7.98
6	1	10.54
1	2	18.32
2	2	18.66
3	2	20.78
4	2	12.46
5	2	18.15
6	2	17.84
1	3	21.11
2	3	23.80
3	3	24.24
4	3	26.05
5	3	23.10
6	3	22.34
1	4	31.43
2	4	31.18
3	4	30.95
4	4	27.96
5	4	31.03
6	4	30.12
1	5	39.95
2	5	39.15
3	5	38.39
4	5	41.82
5	5	46.31
6	5	36.68

OTHER DEVICE

RUN	GAIN	RANGE
1	1	7.78
2	1	4.77
3	1	6.29
4	1	6.83
5	1	5.89
6	1	5.77
1	2	13.87
2	2	13.88
3	2	10.05
4	2	13.33
5	2	14.60
6	2	12.86
1	3	20.80
2	3	20.73
3	3	20.44
4	3	19.97
5	3	20.28
6	3	19.89
1	4	27.52
2	4	26.03
3	4	28.63
4	4	27.84
5	4	29.74
6	4	25.87
1	5	37.86
2	5	38.10
3	5	35.97
4	5	33.93
5	5	34.10
6	5	35.93



TORRO PARK SOFT PACK

LOCATION	DEVICE	STANDARD DEVIATION IN METERS AT GAIN SETTING				
		1	2	3	4	5
Big Sur	Common	0.6856	0.6694	1.7516	0.9100	2.3932
Big Sur	Other	1.5666	0.8639	0.8179	1.6136	4.2278
Torro Park Hard Pack	Common	1.9012	0.5317	1.1999	0.7381	2.6080
Torro Park Hard Pack	Other	0.9014	0.9955	1.0113	1.4591	0.9114
Torro Park Soft Pack	Common	2.1088	2.7738	1.6932	1.2952	3.3641
Torro Park Soft Pack	Other	1.0222	1.6040	0.3783	1.4941	1.7758
Torro Park Sand	Common	1.0142	1.4132	1.1608	1.7421	1.9915
Torro Park Sand	Other	0.6759	1.7480	2.8714	1.3663	1.0582
Creek Bed	Common	0.8663	0.6619	1.0622	2.2262	1.3981
Creek Bed	Other	0.7104	1.1559	1.0297	2.2698	1.5102

BIBLOGRAPHY

1. Bimed 02V, Health Sciences Computing Facility, UCLA.

2. Bimed 01R, Health Sciences Computing Facility, UCLA.

3. Brownlee, K. A., Statistical Theory and Methodology in Science and Engineering, Wiley, 1967.

4. U. S. Army Project Mobile Army Sensor Systems Test Evaluation and Review Activity (MASSTER), MINISID ID Test Report Addendum - The Many-Sid Report, December 1970.

5. U. S. Army Project Mobile Army Sensor Systems Test Evaluation and Review Activity (MASSTER), Guide for Employment of Unattended Ground Sensors, December 1970.

6. U. S. Army Concept Team in Vietnam, Final Report Stano III, Unattended Ground Sensor Combat Evaluation, September 1970

7. Defense Communications Planning Group, Use of Sensors for Tactical Surveillance, May 1969.

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13. ABSTRACT

A review or research indicates that the attenuation of seismic impulses is a complex function of such factors as moisture, soil thickness, substrata homogeneity, substrata consistency, and vegetation. The problem encountered when seismic devices are employed in a tactical situation is the prediction of ranges of detection for different soil types without resorting to soil samples, compression tests, etc. A knowledge of the seismic characteristics or the ranges of detection in various soil types would be very beneficial when employing seismic devices. This thesis will show a relationship, useful for prediction, between the attenuation properties and the range at which a test signal is first detected at a preset level.

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